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Natural Tree Regeneration After Clearcutting in Arizona's Ponderosa Pine Forests: Two Long-Term Case Studies

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Long-term natural regeneration of ponderosa pine (*Pinus ponderosa*), Gambel oak (*Quercus gambelii*), and alligator juniper (*Juniperus deppeana*) was evaluated on two watersheds 23 and 31 years after clearcutting had removed the ponderosa pine forest overstories. On one watershed, where slash had been pushed, piled, and burned, the stocking and density of ponderosa pine seedlings declined, and have shown no increase since the initial post-clearing inventory. However, the stocking of Gambel oak and alligator juniper regeneration increased 1.5 and 2.5 times, respectively, and the density of both species increased from less than 100 stems per acre prior to clearing to almost 1,200 stems per acre 23 years after the treatment. The watershed has been removed from ponderosa pine production, but it still can be managed for fuelwood, forage, and wildlife habitat. On the other watershed, where grass production after clearcutting had been emphasized, relatively few stems per acre of any species were found 31 years after the treatment. Both of the watersheds demonstrated the slow recovery of trees following a major disturbance. If timber production is to be maintained, large clearings resulting from management or natural causes should be planted as soon as possible.

Keywords: Natural regeneration, *Pinus ponderosa, Quercus gambelii, Juniperus deppeana*, clearcuts, Arizona

Introduction

Forest overstories can be removed because of land management activities or natural events, such as fires and insect infestations. Land managers can create and maintain clearcuts to meet production goals for nontimber resources, such as water yield improvement or forage for livestock and wildlife, as has been tested in Arizona's ponderosa pine forests (Baker 1986, Ffolliott et al. 1978). Clearing of forest overstories to increase water yields also has been studied elsewhere in the United States (Bosch and Hewlett 1982). Regardless of the specific effects of these treatments, and unless the clearcut areas are reforested subsequently, these areas will be removed from commercial timber production and the potentials to manage the areas for the full range of multiple-use benefits will be diminished. If timber production is important on sites where natural tree regeneration cannot be relied upon, the initiation of tree planting programs becomes necessary. It is important, therefore, to determine the degree to which the clearcut areas will regenerate naturally when evaluating management alternatives or scheduling specific tree planting programs. Managers need to understand the long-term rates of ecological succession in the clearings and other disturbed areas to plan and, if necessary, to modify management practices. This holds true whether they

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wish to regenerate or maintain the clearings. Long-term observations are central to almost every important ecological concept and to every environmental issue (Franklin 1989); tree regeneration is no exception.

An opportunity to monitor the effects of clearcutting on natural tree regeneration in Arizona's ponderosa pine forests is found on the Beaver Creek watersheds, located about 45 miles south of Flagstaff, on the Coconino National Forest. Two long-term case studies of this monitoring effort are presented here.

Study Areas

The case studies involve two Beaver Creek watersheds on which ponderosa pine forest overstories were clearcut to determine the effects of this "benchmark treatment" on water yields and other multiple-use values (Baker 1986, Brown et al. 1974). The general temperature regime and precipitation, averaging 23 inches annually, on the watersheds are similar to those previously reported by Baker (1986) and Brown et al. (1974). Further descriptions of the two watersheds are given in table 1, and the specific clearcutting treatments imposed on the watersheds are presented below.

To evaluate the potential for water yield improvements, a clearcutting treatment was imposed on Watershed 12 in 1966–67. All merchantable poles and sawtimber were harvested initially, and the remaining nonmerchantable trees then were felled (Baker 1986, Brown et al. 1974). Slash and other debris were windrowed at approximately 100-foot intervals. Gambel oak and alligator juniper were allowed to sprout and grow after the treatment. The treatment prescription did not include the subsequent seeding of herbaceous plants. The slash windrows initially were left in place, but they were burned in the fall of 1977 (Baker 1983). Cattle grazing continued after the treatment in a pattern similar to that of the surrounding area.

The sawtimber overstory on Watershed 11 was clearcut in 1957. Slash and the remaining trees were pushed and piled into windrows, and burned in the spring of 1958. The watershed was seeded in the summer, the principal species planted being intermediate (*Agropyron intermedium*), crested (*A. cristatum*), and western (*A. smithii*) wheatgrasses, and yellow sweet clover (*Melilotus officinalis*). Gambel oak sprouts were treated with herbicides in the spring of 1962; nearly 75% of the plants sampled were killed (Johnsen et al. 1969). The watershed was grazed only by mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) from 1958 through 1967. In 1968, a cattle grazing treatment was prescribed to determine the effects of forage consumption by livestock on multiple-use values (Brown et al. 1974, Ffolliott et al. 1978). The treatment removed 60% of the standing crop of perennial grasses annually by allowing 80 animals to graze the watershed for two periods (May 15-June 15 and Oct. 1-Nov. 15) in each of 5 consecutive years. Since termination of the grazing treatment in 1972, the watershed has been included in the seasonal grazing patterns of the general area.

Methods

Different inventory designs have been used to measure the regeneration on the watersheds in the long period since the studies were begun. The inventories were conducted by different people, often with different immediate objectives; however, the results do provide a history of long-term recovery after major disturbances.

On Watershed 12, ponderosa pine, Gambel oak, and alligator juniper regeneration was measured initially in 1962, 4 years before clearcutting. Stocking (the percent

Table 1.—Description of the two Beaver Creek Watersheds.

Characteristics	Watershed	
	12	11
Physical:		
Area (acres)	425	188
Elevation range (feet)	6,800–7,300	6,450–6,800
Slopes	<15%	<15%
Soils series[1]	Brolliar (Typic Argiustoll) Siesta – Sponseller (Typic Rhodustalf – Argic Cryoboroll)	Brolliar
Pretreatment stand values:		
Basal area (square feet/acre)		
Ponderosa pine	77	74
Gambel oak	14	14
Alligator juniper	13	12
Total	104	100[2]
Volume (board feet/acre)	3,700	2,000
Site class [3]	II	III
Habitat type	*Pinus ponderosa/ Quercus gambelii*	*Pinus ponderosa/ Bouteloua gracilis*

[1]*Soils data from Williams and Anderson (1967).*
[2]*Stand and stocking characteristics for watershed 11 determined from aerial photographs.*
[3]*Schubert (1974) based on Minor's site index values (Minor 1964).*

of plots with at least one tree) and density (the number of stems per acre by species) were measured on 197 permanently located circular sample plots, 1/200-acre in size, arranged in a systematic sampling design with multiple random starts (Shiue 1960). Stocking and the number of stems of only ponderosa pine were inventoried on the sample plots in 1968, 2 years after clearcutting. In 1975, 9 years after the treatment, the number of ponderosa pine stems was measured on a series of 6.6-foot-wide strips, representing a sampling intensity of 1.5% of the area. A fourth inventory of tree regeneration in 1989, 23 years after clearcutting, included measures of stocking and the number of stems by species, using the same design as the 1962 inventory.

On Watershed 11, tree regeneration was not measured before the clearcutting but it has been inventoried twice since the treatment, in 1975 and 1989, 17 and 31 years after clearcutting, respectively. The 1975 inventory, in which the number of ponderosa pine stems was considered, was made on a series of 6.6-foot-wide strips representing a sampling intensity of approximately 2%. In 1989, stocking and the number of trees by species were measured on 137 permanently located circular sample plots, arranged in a similar design and using the procedures described for Watershed 12.

In addition, stems were recorded in terms of the following size classes in the 1989 inventories on both watersheds: less than 4–1/2 feet in height, or by 1-inch d.b.h. classes for taller stems. The stems measured in all inventories represented natural regeneration.

Depending upon the inventory procedure, the measurements obtained were summarized in terms of stocking conditions, number of stems per acre, or both; the confidence intervals presented are at the 95% level.

Results

Watershed 12

Stocking and density of tree regeneration were greatest before the timber harvesting, declined after the treatment, and remained constant until 1989 (fig. 1). Sixty-five percent of the sample plots were stocked with tree regeneration 4 years before clearcutting. Little spatial pattern was observed in these stocking conditions, with tree regeneration apparently being distributed randomly on the watershed.

There were 454 ± 372 ponderosa pine seedlings per acre in 1962 (fig. 1). Gambel oak and alligator juniper regeneration, mostly sprouts, averaged 225 ± 60 and 14 ± 9 stems per acre, respectively.

Only 16% of the sample plots were stocked (fig. 1) with ponderosa pine seedlings 2 years after clearcutting (Heidmann et al. 1977). Seedlings on 5% of the plots had germinated after the treatment, while the seedlings on the other stocked plots had been established before clearcutting. Seedlings established after clearcutting, found scattered throughout the watershed, originated from seed that fell prior to the treatment. Ponderosa pine seedlings were not concentrated at the border of the adjacent uncut forest, as originally expected. There was an average of 38 ponderosa pine seedlings per acre, a decline of about 92%. Gambel oak and alligator juniper were not measured in this inventory.

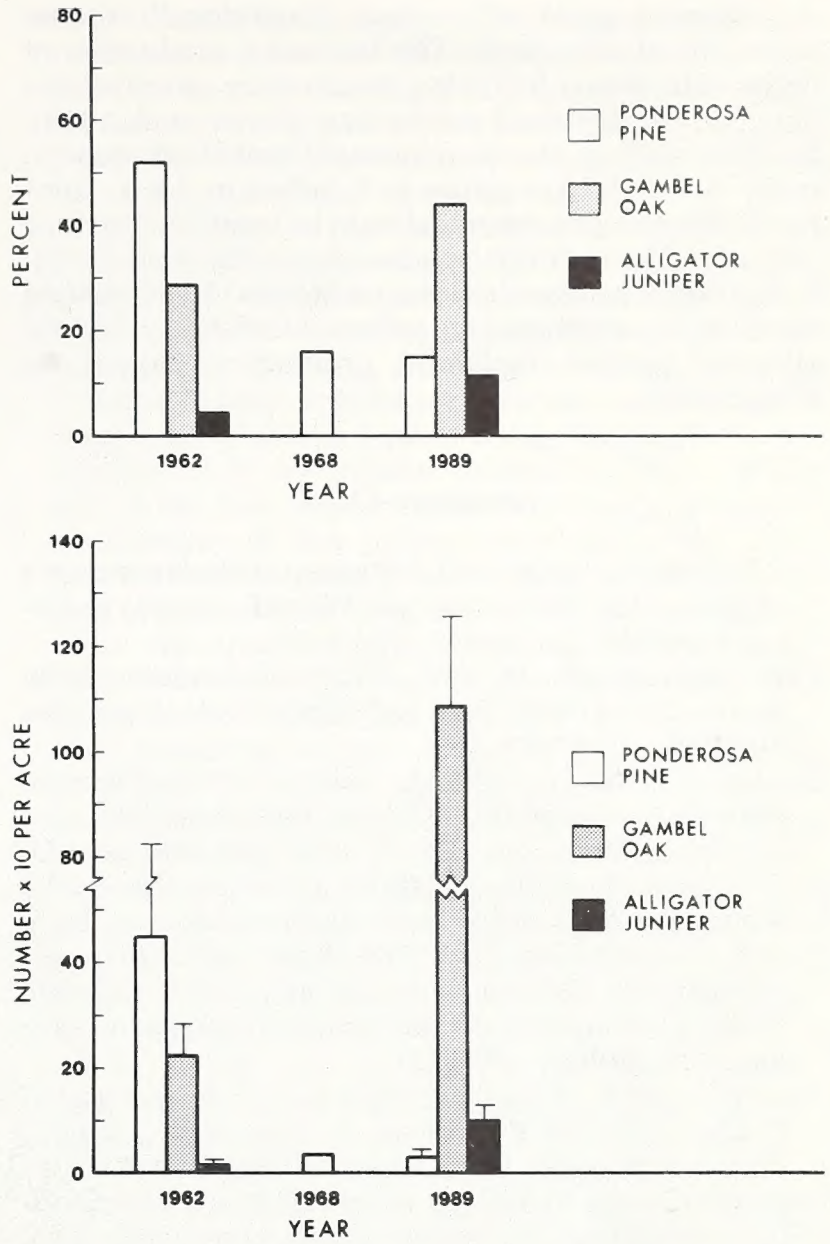

Figure 1.—Stocking and density (with standard error) of tree regeneration on Beaver Creek Watershed 12 in 1962 and 1989, and stocking and density of ponderosa pine only in 1968.

Nine years after clearcutting, there were 109 ponderosa pine seedlings per acre, measured by Heidmann et al. (1977) using the "strip-cruise" inventory method. Most of these seedlings had become established after the treatment. This inventory also supported the earlier finding of little trend in seedling establishment with respect to seed source. Some seedlings were 2,000 feet from the edge of the watershed, the nearest seed source. Gambel oak and alligator juniper were not measured.

Fourteen years later, or 23 years after clearcutting, 56% of the sample plots were stocked with trees (fig. 1). Ponderosa pine stocked 15% of the plots, a stocking condition similar to that observed 2 years after the treatment. Gambel oak and alligator juniper stocking had increased, mostly in the form of sprouts originating after clearcutting. In comparison to the stocking conditions before the treatment, stocking of ponderosa pine was 30% of that measured before clearcutting, while Gam-

bel oak and alligator juniper stocking had increased approximately 1.5 and 2.5 times, respectively (fig. 2).

The 1989 inventory also found 32 ± 10 ponderosa pine stems per acre, a density similar to that tallied 2 years after clearcutting. (The almost threefold increase in density reported in 1975, relative to that observed in 1968 and 1989, has been attributed largely to the different sampling design and greater sampling intensity of the 1975 inventory.) The distribution of regeneration among the four size classes is presented in table 2; the 3-inch d.b.h. class contained 44% of the trees, reflecting growth rates generally associated with saplings on Site II lands.

Gambel oak regeneration averaged 1,090 ± 167 stems per acre, and alligator juniper regeneration averaged 100 ± 32 stems per acre. Approximately half of both the oak and juniper regeneration was in the 1-inch d.b.h. class (table 2). Gambel oak and alligator juniper sprouts were vigorous and appeared to be increasing in density in 1989, although the magnitude of the increases cannot be projected at this time.

Watershed 11

In 1975, seventeen years after clearing, there were less than 5 ponderosa pine seedlings per acre (Heidmann et al. 1977). Gambel oak and alligator juniper were not measured in this inventory.

Fourteen years later, 31 years after clearcutting, only 22% of the sample plots were stocked with tree regeneration (fig. 3). Ponderosa pine stems stocked 6% of the plots, and Gambel oak and alligator juniper each stocked about 8% of the plots. The tree regeneration appeared to be distributed randomly on the watershed.

The 1989 inventory also showed that the densities of tree regeneration were extremely low. Ponderosa pine regeneration averaged 13 ± 9 stems per acre. Two-thirds of the stems were less than 4-1/2 feet in height, with the remaining stems occurring in the 3-inch d.b.h. class (table 2).

Gambel oak regeneration, mostly sprouts, averaged 172 ± 143 stems per acre. Alligator juniper regeneration, also mostly sprouts, averaged 51 ± 25 stems per acre. Most of both the oak and alligator juniper regeneration was in the 1-inch d.b.h. class (table 2).

Figure 2.—Stocking of Gambel oak and alligator juniper increased significantly 23 years after clearcutting Beaver Creek Watershed 12, while ponderosa pine was less than that before the treatment.

Figure 3.—Low density of tree regeneration 31 years after clearcutting Beaver Creek Watershed 11 is attributed largely to competition from seeded herbaceous species, herbicidal treatments to control Gambel oak, and subsequent cattle grazing.

Discussion

Clearcutting treatments, for whatever the purpose, on watersheds as large as the two at Beaver Creek, can

Table 2.—Percentage of the natural regeneration by size class measured in the 1989 inventory.

Species	% < 4.5 ft in height	% in diameter class—		
		1-inch	2-inch	≥3-inch
Watershed 12				
Ponderosa pine	9	19	28	44
Gambel oak	38	49	11	2
Alligator juniper	17	55	21	7
Watershed 11				
Ponderosa pine	67	0	0	33
Gambel oak	36	61	2	1
Alligator juniper	25	49	9	17

remove the areas from subsequent tree production, especially by ponderosa pine. While 56% of the area on Watershed 12 was stocked with trees 23 years after clearcutting, only 15% of the area was stocked with ponderosa pine. Furthermore, the stocking of ponderosa pine stems has remained largely unchanged since the treatment. The density of ponderosa pine stems also is inadequate for sustainable forest production. The 32 ponderosa pine stems per acre is far less than the 2,000 seedlings prescribed for adequate stocking of clearcut lands by Pearson (1950) and Schubert (1974), and only about 11% of the current standard, which calls for 300 established trees per acre (Bassett 1990,[2] pers. comm.).

The lack of ponderosa pine regeneration on Watershed 12 is attributed to an insufficient seed source, particularly in the "center" of the watershed, damage during slash cleanup to trees that initially survived the timber harvest, and the detrimental site and initial growth conditions frequently encountered in Arizona's ponderosa pine forests (Pearson 1950, Schubert 1974). Regeneration is particularly difficult in soils developed from basalt because of frost heaving and drought problems (Heidmann et al. 1982). Gambel oak allelopathy also may retard the growth of new ponderosa pine seedlings, contributing to limited natural regeneration on many sites in the Southwest (Harrington 1987). Competition from the apparently increasing numbers of Gambel oak and alligator juniper sprouts also could have been a problem for ponderosa pine regeneration, although some observations indicate a brush cover may not be detrimental. Gambel oak is becoming established to the point where Watershed 12 essentially has been converted to an "oak-brush field" (fig. 2). It will be a long time before the successful establishment and survival of natural ponderosa pine regeneration can occur, even if a seed source becomes available and favorable site and initial growth conditions are present. Watershed 12 still can be managed under multiple-use principles, however, since the Gambel oak and alligator juniper are important fuelwood species (Barger and Ffolliott 1972) and supply important food and cover for wildlife (Reynolds et al. 1970). Clearing of ponderosa pine forest overstories in Arizona has also generally produced increases in streamflow volumes, at least in the short-term (Baker 1986). Managers may prefer to maintain the present cover rather than to reemphasize the timber management option.

The situation is even less encouraging for future timber production on Watershed 11, where ponderosa pine stems are absent, for the most part, and Gambel oak and alligator juniper regeneration is only slightly better. This lack of natural tree regeneration is due largely to the factors listed above, the competition from the perennial grasses and clover seeded as part of the initial treatment, and, to some extent, to the intensive cattle grazing treatment subsequently imposed on the watershed in the spring and fall between 1968 and 1972. The relatively poor regeneration of Gambel oak also can be related to the herbicide treatments in the 1960s (Johnsen et al. 1969). Furthermore, there appeared to be little increase in the density of tree regeneration in recent years, as the stems measured were well established. It seems improbable that tree regeneration will improve significantly in the future; Watershed 11 has been removed from tree production for all practical purposes, and essentially has become an "artificial" grassland (fig. 3).

Representing but two case studies, the results obtained here must be interpreted with caution. It does appear, however, that obtaining adequate natural tree regeneration, especially of ponderosa pine, after clearcutting of large areas is unlikely, a finding that is not surprising. Current federal regulations require satisfactory tree regeneration within 5 years of the final harvest, if the objective of the cut is timber production. The slow recovery of the two Beaver Creek watersheds would be a justification of this policy, especially where timber production is important in the multiple-use mix. If not part of a long-term evaluation effort, or designated for other resource management goals, both watersheds would have to be planted with ponderosa pine seedlings by current standards; this would be difficult on these "old clearcuts" because of the need for intensive site preparation to limit the competition between the planted seedlings and the existing brush and herbaceous species. These areas also can support pocket gopher (*Thomomys bottae*) populations, which can limit the success of tree planting operations (Gottfried and Patton 1984). Regeneration activities should be started as soon as possible after timber harvesting activities or wildfire to reduce these problems. Heidmann et al. (1982) indicated that satisfactory natural regeneration of ponderosa pine can occur if a site has an adequate seed source, mechanical site preparation, rodent control, and exclusion of livestock grazing for 3 to 5 years.

In interpreting the results of this study, it is important to keep in mind that these case studies represent two watersheds on basaltic soils. Natural regeneration of ponderosa pine is less successful, generally, on these soils than on soils of sedimentary parent materials (Heidmann et al. 1982). It also should be remembered that the two watersheds studied are classified in Site Classes II and III. Natural tree regeneration after clearcutting of areas in Site Class I has not been studied. However, it would be of interest to continue monitoring the two watersheds in the future to determine the nature of long-term succession in these ponderosa pine forests.

Conclusions

Clearcutting of ponderosa pine forests on two Beaver Creek watersheds resulted in limited natural tree regeneration after the treatments. It is unlikely, therefore, that either of these watersheds can be managed for tree production in the foreseeable future without an artificial regeneration program. Clearcuts must be planted soon after treatment when the objective of management is to maintain a ponderosa pine forest.

Although removed from tree production at this time, the two watersheds have other multiple-use potentials. Managers actually could favor nontimber resource

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management goals rather than "traditional" timber management objectives. The increased production of herbaceous plants following clearcutting improves the potentials for livestock production (Brown et al. 1974). On Watershed 12, the abundance of Gambel oak sprouts, many of which have grown to 3 inches in d.b.h. since the clearcutting treatment, should be beneficial to mule deer and other wildlife species (Reynolds et al. 1970). A short-term increase in water yield from this watershed also was important, and the potential for Gambel oak and alligator juniper fuelwood production should be considered.

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